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Subject: Chlorophyll target models for North Dakota lakes

## MODELS

The goal of these analyses was to identify chlorophyll a concentration targets associated with aquatic life and recreation uses in North Dakota lakes. Drinking water uses were considered, but drinking water in North Dakota comes primarily from drinking water sources with the exception of Lake Sakakawea which was not included in the statewide lakes analysis but rather through a separate lake-specific evaluation. Four relationships were considered, outlined in the table below and described in detail in subsequent sections. North Dakota state data were used to develop models for pH~chlorophyll and microcystin~chlorophyll, and an application of EPA's Ambient Water Quality Criteria to Address Nutrient Pollution in Lakes and Reservoirs (2021) was made for dissolved oxygen (DO)~chlorophyll, zooplankton~chlorophyll, and microcystin~chlorophyll. Chlorophyll targets were generated from each model where possible.

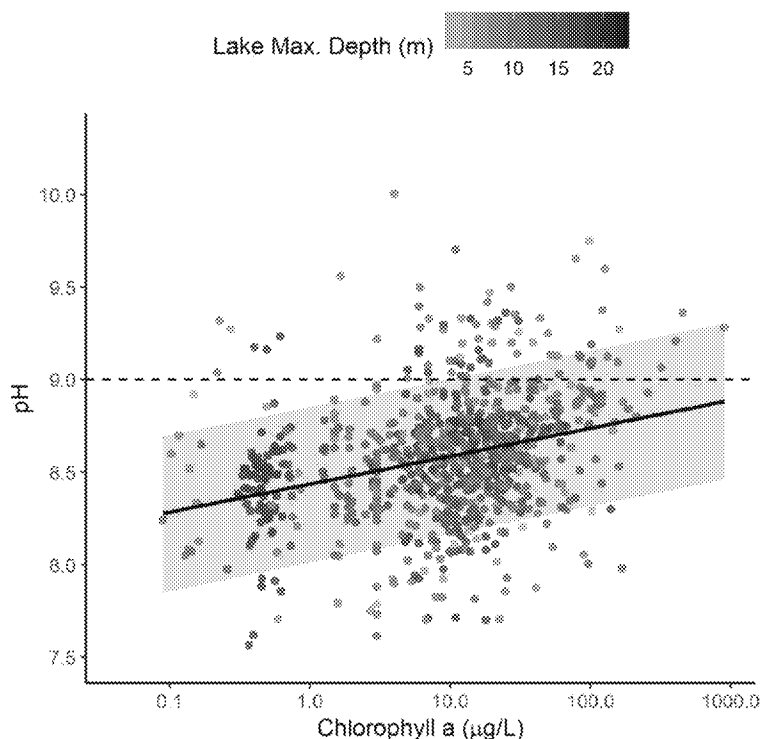
Model	State model	National model	Designated Use
pH ~ chlorophyll	x		Aquatic Life
Dissolved oxygen (DO) ~ chlorophyll		x	Aquatic Life
Zooplankton ~ chlorophyll		x	Aquatic Life
Microcystin ~ chlorophyll	x	x	Recreation

## pH ~ Chlorophyll

The process of photosynthesis increases pH, so we expect to see higher pH at higher chlorophyll concentrations (assuming lakes are sampled in the daytime). A linear regression was developed from grab samples of surface pH and log-transformed chlorophyll (i.e., the individual observations dataset). The rationale for developing the model from grab samples was that pH standards are evaluated using instantaneous measurements rather than temporally aggregated (e.g., seasonal average) samples. In North Dakota lakes, there was a positive correlation between chlorophyll and pH (linear regression,  $df = 859$ ,  $R^2 = 0.09$ ). This relationship was statistically significant but displayed a substantial amount of scatter inherent in the relationship, so this model alone will likely not be used in determining chlorophyll targets for the protection of aquatic life uses.

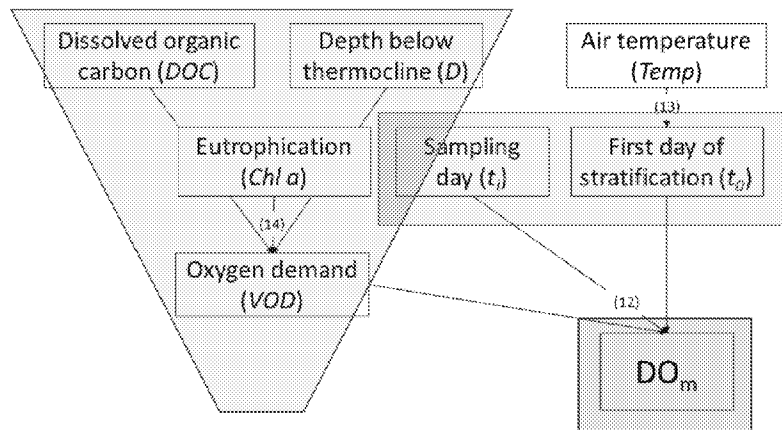
An 80<sup>th</sup> prediction interval was evaluated for the linear regression, consistent with the assessment procedure North Dakota employs that allows a 10<sup>th</sup> percentile pH exceedance. Essentially, an 80<sup>th</sup> prediction interval predicts that 80% of future pH values measured at a given chlorophyll concentration will be located within the range of the prediction interval, bounded at 10% on the upper end and 10% on the lower end. This approach inherently provides a margin of safety. Since pH values above 9 are considered exceedances of North Dakota's pH criterion, the point at which the upper prediction interval crosses a pH of 9 can be considered the chlorophyll target in this case. **The chlorophyll target for the pH model with an 80<sup>th</sup> prediction interval was 10  $\mu\text{g/L}$ .**

North Dakota is interested in employing maximum lake depth in its categorization system for lakes, so lake depth was evaluated as a potential factor in the pH-chlorophyll relationship. Lake depth was found not to be a significant predictor of pH and did not have a significant interaction with chlorophyll, with pH exceedances occurring across lake depths and a lack of a distinct pattern of chlorophyll concentrations across lake depths.



## Dissolved Oxygen (DO) ~ Chlorophyll

The national DO model (also called the “hypoxia model”) assumes that hypolimnetic dissolved oxygen ( $DO_m$ ) sampled on any given day ( $t_i$ ) is a function of the time since the hypolimnion was isolated from the atmosphere (time since first day of stratification;  $t_0$ ) and the volumetric oxygen demand of the water volume in the hypolimnion (VOD). VOD is a function of the depth below the thermocline as well as the amount of carbon available to be respired (approximated from dissolved organic carbon and chlorophyll concentration). The model supposes that in seasonally stratified lakes, there may be a period during the stratified period when the epilimnion temperature is higher than the temperature optimum for fish species, and the cooler waters of the hypolimnion must have sufficient oxygen during this time to support fish species. This model does not explicitly consider lake classes but rather conditions present in an individual lake to establish chlorophyll targets. Results can be pooled or aggregated to establish chlorophyll targets for groups of lakes, such as those classified by depth.

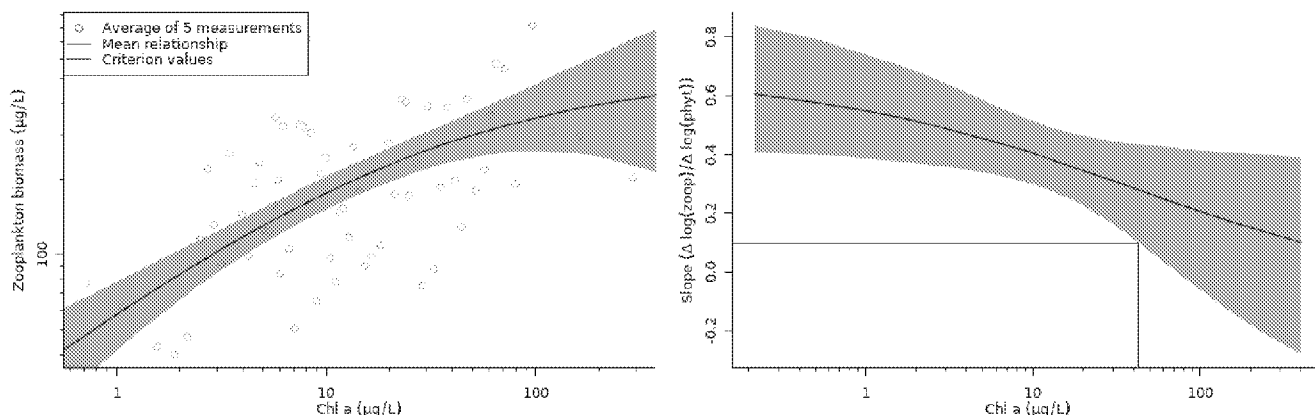


North Dakota Class II lakes were added to the hypoxia model, and a cool-water temperature threshold of 24°C was chosen to represent temperatures relevant for walleye along with a DO threshold of 5 mg/L (consistent with North Dakota standards) and a refuge depth of 1 m. Supplied with these settings, the model output indicated that lakes in North Dakota did not consistently reach this temperature threshold. Thus, lakes did not experience the “thermal squeeze” that would necessitate protection of a minimum DO target in the hypolimnion, and **no chlorophyll target was identified from this model application.**

A few considerations should be made when interpreting the output for the national hypoxia model. First, North Dakota staff indicated that ice off for lakes generally occurs around April 15, which can be variable depending on winter and spring weather conditions. The model indicated that the predicted first date of stratification was April 10 at 300 m elevation (the lowest elevation lake in the North Dakota dataset) and April 29 at 950 m elevation (the highest elevation lake in the North Dakota dataset). These dates appear to be too early given the observed spring phenology in North Dakota lakes, so output should be considered conservative. Second, a lower temperature threshold for cold-water fish of 18°C was considered, due to the presence of native and/or stocked rainbow trout in some lakes. These fish species may be considered “resident” even if stocked, according to EPA’s Revised Deletion Process for the Site-Specific Recalculation Procedure for Aquatic Life Criteria (1994). Finally, the model is sensitive to DOC concentration, depth below the thermocline, and certainty level. To complete the model run for a lower temperature threshold, we would need to establish ranges for these parameters through discussions with North Dakota.

## Zooplankton ~ Chlorophyll

The zooplankton national model analyzes the relationship between primary producers (chlorophyll) and primary consumers (zooplankton) in the water column in lakes. Under oligotrophic conditions, it is expected that zooplankton biomass will increase as phytoplankton biomass increases. As chlorophyll concentrations increase and become more eutrophic, however, the connection between zooplankton and phytoplankton biomass becomes decoupled and the zooplankton response levels off. The model user can select a threshold for this relationship that protects against that decoupling.

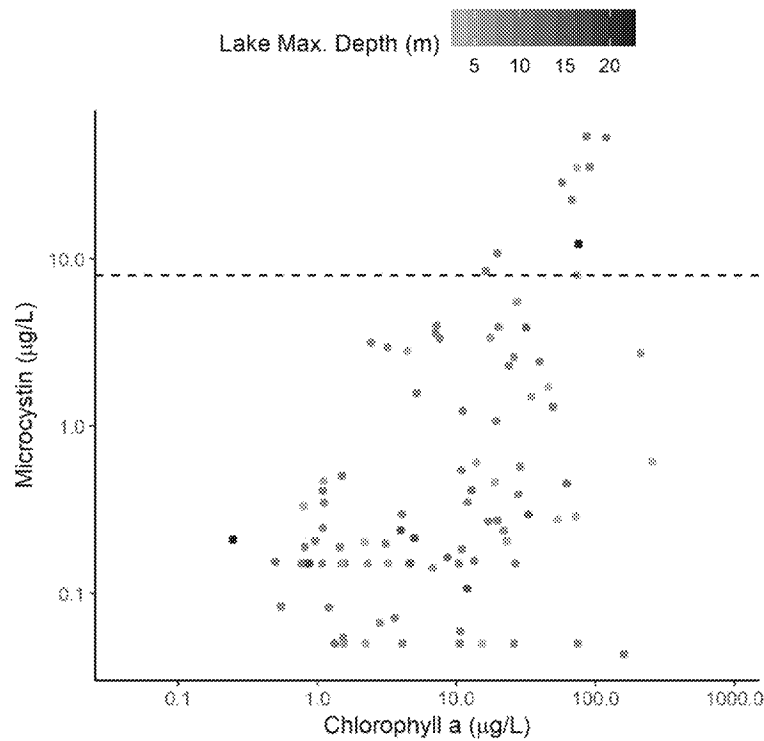


North Dakota did not have zooplankton data to incorporate into the national model, so the model was run with the National Lakes Assessment data alone (which include lakes in North Dakota). This model thus will not likely serve as the primary basis for selecting a chlorophyll target. Slope thresholds of 0.1 and 0.2 were evaluated with the rationale of a lower slope threshold to provide protectiveness while relying on national-level data that is less specific to North Dakota. High certainty levels of 0.90-0.95 were evaluated to provide a higher degree of certainty associated with low slope thresholds (i.e., seek to be very sure of chlorophyll targets because they approach the tipping point at lower slope thresholds). **The following chlorophyll targets were identified for the three lake depth classes**, with the lower target representative of a 0.90 certainty level and the higher target representative of a 0.95 certainty level:

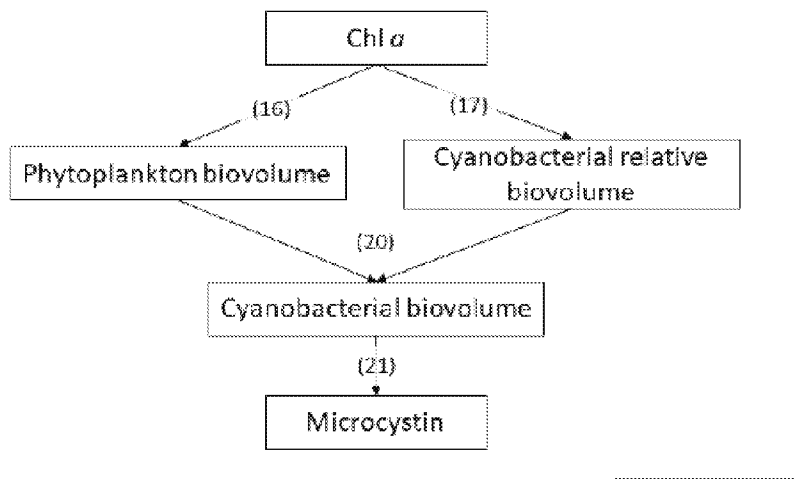
Depth Class	Slope Threshold = 0.1	Slope Threshold = 0.2
<3.8 m	36-43 µg/L	20-23 µg/L
3.8-8.0 m	4-6 µg/L	No target (lower bound exceeded)
>8.0 m	6-7 µg/L	4 µg/L

# Microcystin ~ Chlorophyll

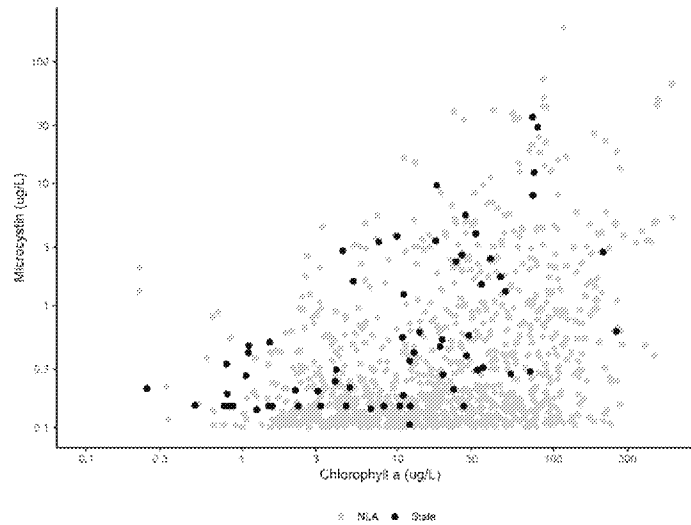
North Dakota has microcystin data for several of its lakes, mostly in eastern lakes. Microcystin exceedances of 8 µg/L occurred across a chlorophyll range of 16-160 µg/L. While microcystin exceedances occurred only at high chlorophyll concentrations, high chlorophyll concentrations were not necessarily predictive of high microcystin concentrations; low microcystin concentrations were found across a range of chlorophyll concentrations.



The national model for microcystin relates microcystin to chlorophyll through cyanobacterial biomass. The North Dakota state-specific data did not include cyanobacterial biomass, so rather than estimating cyanobacterial biomass to update the model with North Dakota data, we applied the model and compared the output with North Dakota data.



North Dakota data (black points) overlap well with range of national data in the model (gray points), suggesting that the national model application is appropriate and representative for North Dakota data.



The microcystin target was selected as 8 µg/L according to the national recreational cyanotoxin criteria. These criteria also specify frequency of exceedance during 10-day assessment windows. Impairments occur when more than 3 exceedances occur over a 100-day season. The allowable exceedance choice for the model represents the daily exceedance probability, which can be translated into a seasonal exceedance probability. An allowable exceedance probability of 0.03 was chosen, representing a probability of 3% the microcystin target would be exceeded on any given day and approximately a 25% probability that greater than 3 excursions in a season. Certainty levels of 0.75, 0.85, and 0.95 were tested. **The following chlorophyll targets were identified:**

Certainty Level	Chlorophyll Target
0.75	12.9 µg/L
0.85	8.6 µg/L
0.95	4.1 µg/L

# CHLOROPHYLL TARGETS

## Aquatic Life

Model	Target	Derivation
pH ~ chlorophyll	10 µg/L	State model: linear regression with 80% prediction interval and pH target of <9
DO ~ chlorophyll	No target	National model application with a temperature threshold of 24°C
Zooplankton ~ chlorophyll	20-43 µg/L (<3.8 m depth) 4-6 µg/L (3.8-8.0 m depth) 4-7 µg/L (>8.0 m depth)	National model application with a slope threshold of 0.1-0.2 and a certainty level of 0.90-0.95.
ND current target	20 µg/L	
MN Aquatic Life Criteria	3 µg/L (cold, lake trout lakes) 6 µg/L (cold, trout lakes) 35 µg/L (cold, south) 30 µg/L (Ecoregion 46 cool and warm, shallow lakes) 22 µg/L (Ecoregion 46 cool and warm, lakes/reservoirs)	

## Recreation

Model	Target	Derivation
Microcystin ~ chlorophyll	4.1-12.9 µg/L	National model application with a microcystin target of 8 µg/L, a 0.03 allowable exceedance, and a certainty level of 0.75-0.95.